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The science behind codes and standards for safe pedestrian walkways: Lighting and visual cues

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A R T I C L E I N F O

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A B S T R A C T

Background: Walkway codes and standards are created through consensus by committees based on a number of factors, including historical precedence, common practice, cost, and, sometimes, empirical data. The authors maintain that codes and standards that can have an impact on human safety and welfare should give consideration in their formulation to the results of pertinent scientific research.
Purpose: This article extends a companion one in examining many elements of common walkway codes and standards related specifically to lighting, warnings and markings. It indicates which elements are based on or supported by empirical data; and which elements could benefit from additional scientific research.
Practical applications: This article identifies areas in which additional research leading toward scientific based codes and standards may be beneficial in enhancing the safety of pedestrian walkway surfaces.

1. Introduction

Falls that result in serious injury and even death remain a major public health concern (Bakken et al., 2007; NSC, 2014; Union-Tribune San Diego, July 4, 2014). A companion article concerning the science behind codes and standards for safe pedestrian walkways deals specifically with the topics of level walkways, stairways, stair handrails and slip resistance (Nemire et al., in press). This second article extends the first by dealing with the scientific basis for pedestrian safety codes and standards for lighting and perceptual cues, i.e., mainly visual cues, as vision is the primary sensory channel of information we utilize when ambulating about our environment.

In so doing, this article deals with the foundational behavioral science as well as the specific scientific research foundation underlying present lighting or illuminance codes and standards as well as the perceptual/cognitive basis for the visibility/conspicuity of objects contributing to pedestrian safety. Further, gaps in present knowledge are also acknowledged as potential areas for furthering the empirical research bases for both present and future safety codes and standards development. While scientists are not the arbiters of safety, science can help make explicit the tradeoffs in adopting different standards in terms of human performance, welfare, and safety.

2. Emergency lighting

About seven months after the Triangle Shirtwaist Factory fire a law was passed, the Sullivan-Hoey Law, that established the New York Bureau of Fire Prevention (Marsico, 2010). Prior to the law's passage, New York fire commissioners did not have the authority to require premise owners to provide adequate fire safety procedures,

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signage, and escape routes (ibid.). In 1913, the Illuminating Engineering Society assisted in formulating the lighting section of the labor law of New York (Osterhaus, 1993). Today, the primary codes and standards that are concerned with emergency egress lighting include: International Building Code (IBC); National Fire Protection Association (NFPA) 101: *Life Safety Code*; British Standard and European Standard (BS EN) 1838; and the *Lighting Handbook*, Recommended Practices (RP), and Design Guides (DG) of the Illuminating Engineering Society (IES).

Section 7.9.2.1 NFPA 101 (2009) states, “Emergency lighting facilities shall be arranged to provide initial illumination that is not less than an average of 1 ft-candle (10.8 lux) and, at any point, not less than 0.1 ft-candle (1.1 lux) measured along the path of egress at floor level.” This differs from IBC (2012) Section 1006.2: “The means of egress illumination shall not be less than 1 fc (11 lux) at the walking surface.” The difference between these two codes is, in part, due to the gauge specified for the criterion value, e.g., *minimum* of 1 fc versus an *average* of 1 fc.

Since illuminance is the density of light (luminous flux) incident on a surface, where the measurement is taken relative to the position of light sources is important in the evaluation of compliance to various codes. A recommended practice approved by both the American National Standards Institute (ANSI) and the Illuminating Engineering Society of North America (IESNA) specifies the locations for assessing lighting. According to ANSI/IESNA RP-1-04 Section 10.3: “The minimum recommended illuminance at the beginning of emergency operation is 10 lux (1 fc) along the centerline of the path of egress and 1 lux (0.1 fc) along a one meter (3.3 foot) band throughout the means of egress.” By comparison, BS EN 1838:2013 Section 4.2.1 requires 1 lux (0. 1 fc) along the centerline and 0.5 lux (0.05 fc) within the one-meter center band.

There is a lack of consensus as to what constitute adequate emergency egress lighting. We (the authors) maintain that the results of scientific research on emergency lighting should be given significant weight in the formulation of codes, standards, and recommended practices. While scientists are not the arbiters of safety, science can help make explicit the tradeoffs in adopting different standards in terms of human performance, welfare, and safety.

2.1. Emergency lighting research: illuminance

Emergency lighting studies have employed several measures of the ability of subjects to safely traverse escape routes under different illuminance conditions. The major dependent variables have been mean speed to reach an exit; mean number of collisions, or near collisions, with objects over the escape route; and the perceived difficulty of moving over the escape route under the different lighting conditions (e.g., Boyce, 1986; Jaschinski, 1982; Mulder and Boyce, 2005; Ouellette and Rea, 1989; Simmons, 1975; Webber and Hallman, 1987).

Simmons (1975) recommended a minimum illuminance of 0.28 lux along the escape corridor at floor level to enable one person at a time to exit a room. The basis for the recommendation was the illuminance condition that yielded both the fastest mean travel times and zero collisions. While Simmons (1975) conducted a pilot study that indicated that subjects older than 50 took longer to move through the escape routes under the lower illuminance conditions than younger subjects, age was not treated as an independent variable in his main experiment.

Jaschinski (1982) divided subjects into two age groups, 18–30 and 50–70. In a pilot study, he found that subjects did not collide with obstacles even under the lowest illuminance condition, 0.24 lux). As a result, he eliminated collisions as a dependent variable and replaced it with a measure that required more attention. According to the capacity model of attention, the more demanding the primary task, the less spare capacity remaining to perform a secondary task (Ogden et al., 1979). The secondary task in Jaschinski's (1982) study was adding numbers played over a loudspeaker.

On the basis of travel times, error rates on the secondary task, and subject evaluations, Jaschinski (1982) recommended an emergency illuminance of 2 lux in general and 4 lux in settings with “many elderly people Jaschinski's recommendations were subject to an important caveat. People do not see the light that strikes a surface, which is illuminance, but the light that a surface reflects or transmits, which is luminance. Therefore, recommended illuminance levels should be adjusted to account for the reflectance values of floors, walls, and ceilings (ibid.). In Jaschinski's (1982) study, room surfaces had a mean reflectance value of approximately 0.50. Conventional floor reflectance is about 0.20 (Mulder and Boyce, 2005). If room surfaces have a lower mean reflectance, the recommended illuminance should be increased.

Ouellette and Rea (1989) reviewed the research literature on emergency egress lighting. The primary independent variables included whether one, four, six, or more subjects simultaneously traversed the route (“crowd size”); their familiarity with the route; level of illuminance prior to the onset of emergency lighting; whether the route was obstacle free; the presence of steps and stairways; if the route contained luminous or non-luminous exit signs; and the age of subjects. They concluded that a mean illuminance of 0.5 lx on the floor of the escape route was sufficient to ensure movement without collisions with large objects.

In Boyce's (2003) review of the research on escape route lighting, he found remarkable agreement in the relationship between speed of movement under typical office lighting and progressive reductions in mean speed as illuminance was decreased. He reported that at 10 lux there is about a 10 percent reduction in mean speed for younger people and 18 percent reduction for older people (age > 50) relative to their mean escape speed for 300 lux (typical office lighting). At 1 lux, the reduction in speed is about 25 percent for younger people and 32 percent for older people. Ouellette and Rea (1989) estimated the reduction in mean speed at 0.2 lux is about 30 percent for younger people (age 18–33) and 50 percent for older individuals (age 50–70) relative to their average speed for 300 lux.

The subjective evaluation of study participants across studies indicates that, in general, they perceived the conditions in which illuminance was relatively high as being the least difficult. Jaschinski (1982) reported that subjects were equally satisfied with mean illuminances of 3.85 lux and 7.7 lux. The subjects in Boyce's (1986) study perceived the 7-lux condition as the least difficult and providing, overall, the most satisfaction (Boyce, 2003; Ouellette and Rea, 1989).

We conclude that the research largely supports those standards and recommended practices that have adopted as a minimum an average illuminance of 10 lux (1 fc) and, at any point, not less than 1 lux (0.1 fc) measured along the path of egress at floor level. This opinion is consistent with the one expressed by Boyce's (2003).

2.2. Emergency lighting research: need to account for mesopic conditions

Mulder and Boyce (2005) observed that none of the codes provided detailed direction for the selection of light sources based on their spectrum. They further observed that the product of the illuminances specified in the codes with the reflectances usually found in buildings likely resulted in luminances requiring mesopic rather than photopic vision.

Mesopic vision spans a luminance range of several log units, between about 0.001 and 10 cd/m^2 (CIE 191:2010, IES, 2011). The